

Current Status of $K^+ \rightarrow \pi^0 \mu^+ \nu_\mu \gamma$ study

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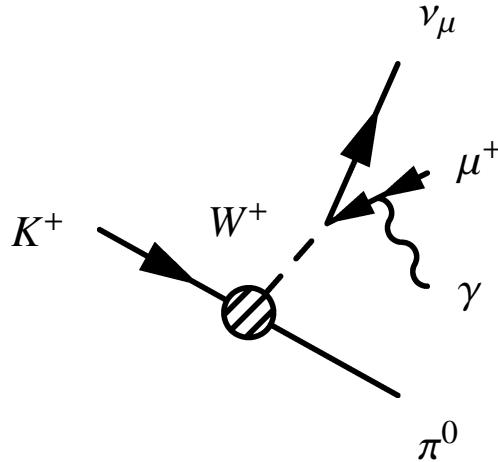
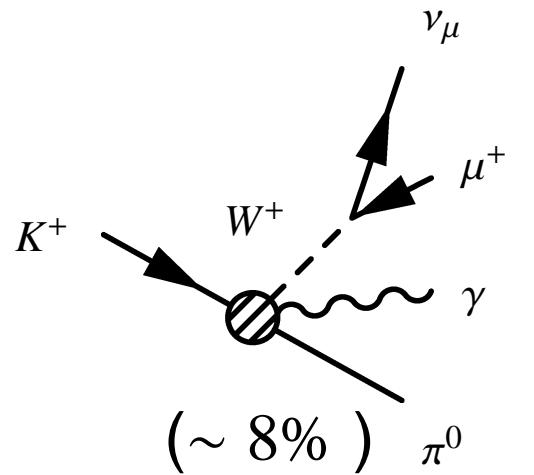
- ★ Introduction
- ★ Current Status of Data analysis: upgrade points.
 - Background estimations
 - F_s estimation
- ★ Analysis schedule
- ★ Summary

Physics Motivations

Chiral Perturbation Theory

QCD effective theory in low energy region
quark field → pseudoscalar meson field

(using Only Chiral Symmetry)



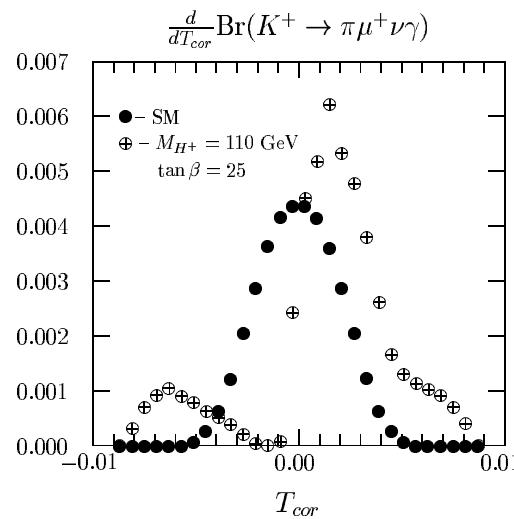
Structure Dependent

Branching ratio is predicted as $\sim 2.0 \times 10^{-5}$
($E_\gamma > 30\text{MeV}, \theta_{\mu\gamma} > 20^\circ$)

Internal Bremsstrahlung

T-violation

asymmetry of $\underline{P_\pi \cdot (P_\mu \times P_\gamma)}$



$$T_{cor} = P_\pi \cdot (P_\mu \times P_\gamma) / m_K^3$$

(from hep-ex/0011033)

The above figure cited before is wrong.

The correct calculations are explained in hep-ph/0305067,
hep-ph/0106147. the precise examination is not done yet.

Experimental Status

Previous exp. @ Argonne National Laboratory (PR D8 1307([1973](#)))

No events were observed. :

$$BR < 6.1 \times 10^{-5} (CL = 90\%)$$

No observation yet!

Other $K_{l3\gamma}$ decays are already measured...

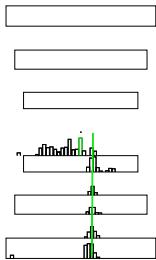
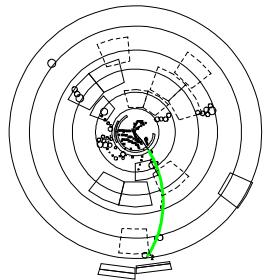
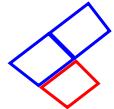
- ★ $K_{e3\gamma}^+ \dots (2.62 \pm 0.20) \times 10^{-4}$
- ★ $K_{e3\gamma}^0 \dots (3.62^{+0.26}_{-0.21}) \times 10^{-3}$
- ★ $K_{\mu3\gamma}^0 \dots (5.7^{+0.6}_{-0.7}) \times 10^{-4}$

Structure Dependent Term: NOT MEASURED!

Event Display

3Gamma

SCALE 1:16.0



RUN
EVENT

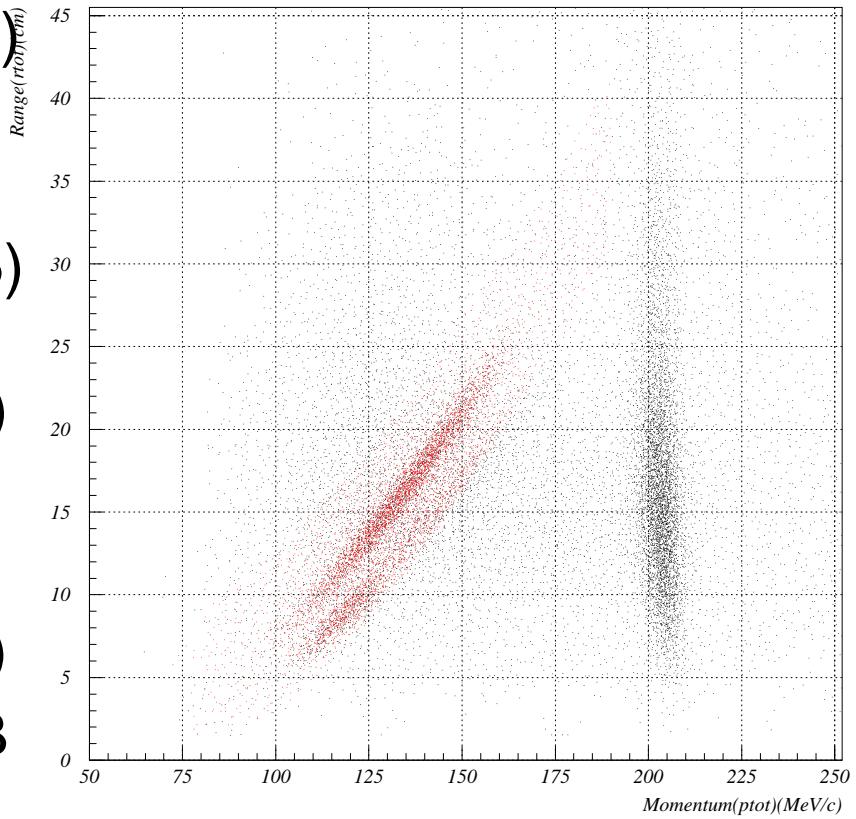
39415
426

- ★ 3 γ clusters in Barrel Veto
- ★ Right Stopping Counter
- ★ No Extra Activity

G3PASS1/G3PASS2

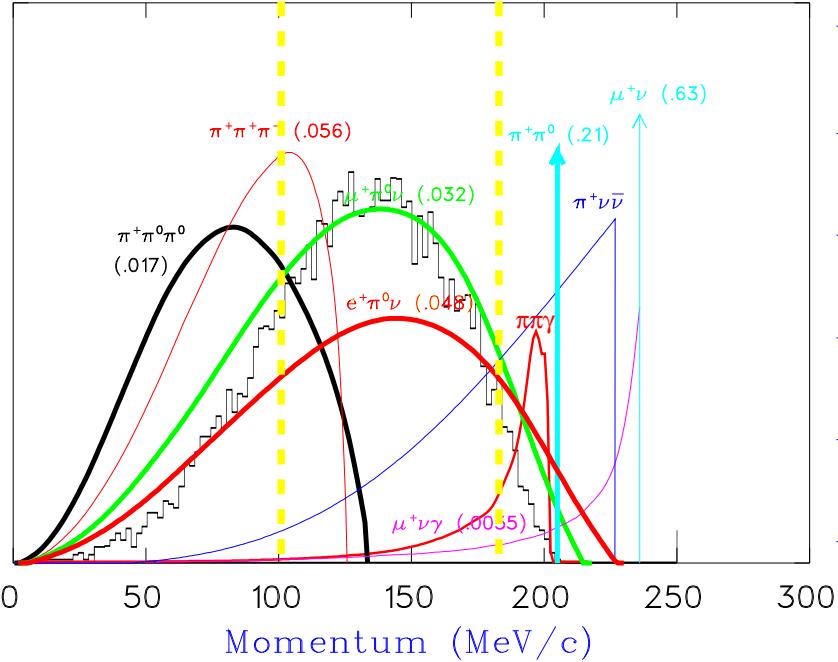
- ★ PASS1 (common to $K_{\mu 3\gamma}/K_{\pi 2\gamma}$ ana.)
 - Data Set: DLT * 35
 - Number of KB_LIVE: 1.86×10^{12}
(1.4 times larger than that of '95)
 - Data Reduction:
 $1\text{TB} \rightarrow 346\text{GB}(33.8\%)(\text{DLT}^*13)$

- ★ PASS2 (for $K_{\mu 3\gamma}$)
(not so tight for Background study)
 - Data Reduction: $346\text{GB} \rightarrow 60\text{GB}$

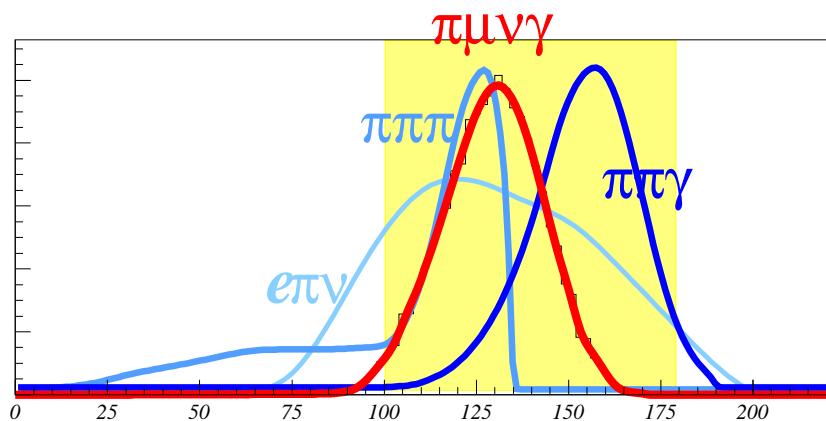


Backgrounds Sources

Arbitrary Units



(After 3gamma trigger) \Rightarrow



- ★ $\pi^0\mu^+\nu_\mu$ +accidental/splitted γ
- ★ $\pi^0e^+\nu_e$ +accidental/splitted γ
- ★ $\pi^+\pi^0\pi^0$ +missing/overlapping γ
- ★ $\pi^+\pi^0\gamma$
- ★ $\pi^+\pi^0$ +accidental/splitted γ
- ★ $\pi^0\pi^0\mu^+\nu_\mu$ negligible??

or
classification by # of γ s

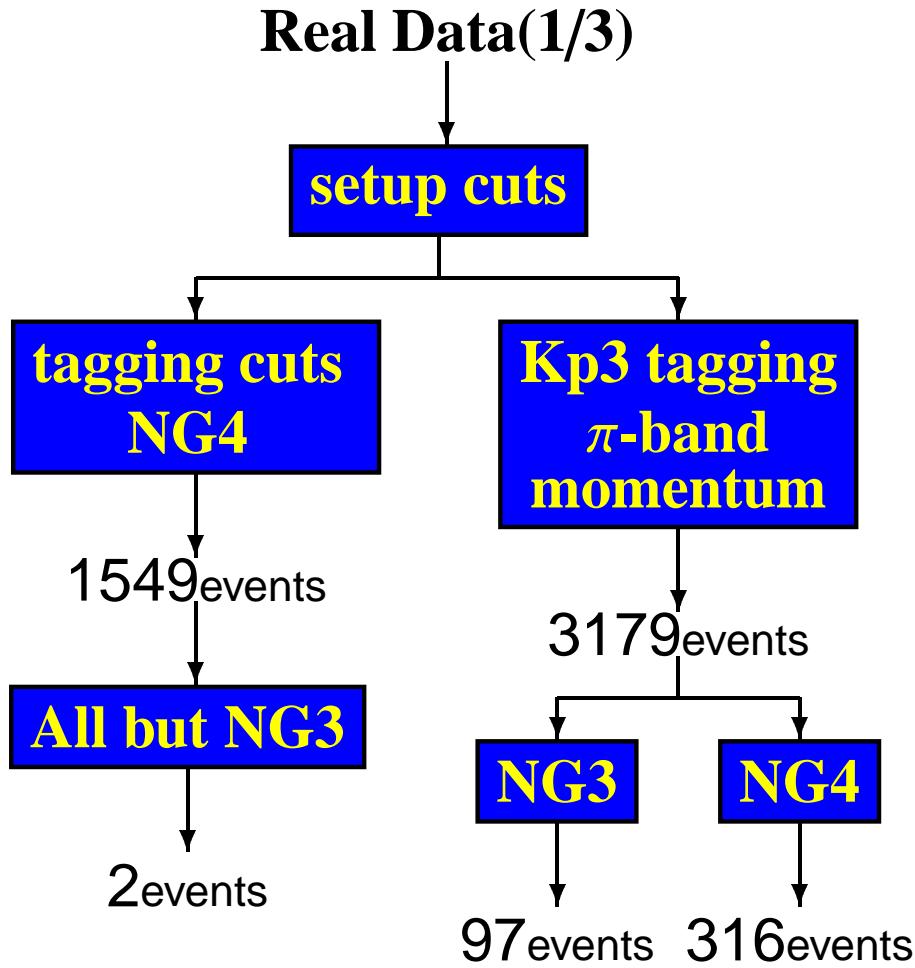
- ★ 4γ + 1 γ is missed and/or charged track miss-ID
- ★ 3γ + charged track miss-ID
- ★ 2γ + fake γ and/or charged track miss-ID

what were problems

- ★ background estimation was still imperfect.
 - $K_{\pi 3}$ bifurcation design. poor rejection.
 - $K\pi 2\gamma$ background no concrete estimation.
- ★ F_s measured by 3gamma data was not consistent with other measurements.

$K_{\pi 3}$ Background(BV-inefficiency)

Using Bifurcation techniques



$$\# \text{ of } K_{\pi 3}\text{-backgrounds} = 2 \times \frac{97}{316} = \underline{\text{0.614}}$$

$K_{\pi 3}$ bifurcation details

- ★ **setup cuts**

itgqualt,cos3d,beam quality cut,tgz, photon veto, $\frac{dE}{dx}$ cut

- ★ **tagging cuts(NG4)**

nreg=4 , γ cluster timing($t_{win} = 2.5\text{nsec}$) overlapping photon cut, splitted γ -cluster cut,extra γ cut

- ★ **All but NG3**

$\chi^2(K_{\mu 3}), \chi^2(K_{\mu 3\gamma}), \mu$ -band cut

- ★ **Kp3 tagging**

π -band(on *rrs-pdc* plane), $100.<\text{ptot}<115.$

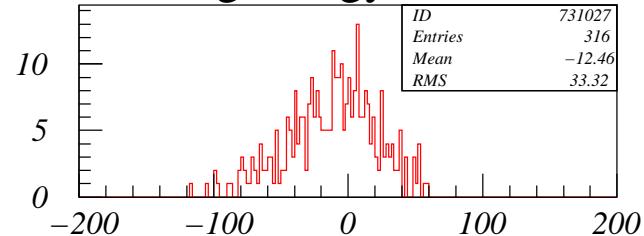
- ★ **NG3**

nreg=3,overlapping photon cut,splitted γ -cluster cut,extra γ cut, γ cluster timing,**missing energy cut**

$K_{\pi 3}$ background estimation

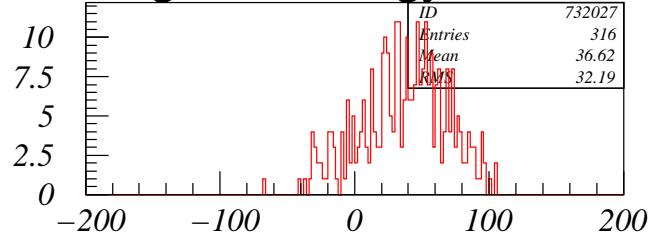
(In 4gamma tagging)

missing energy



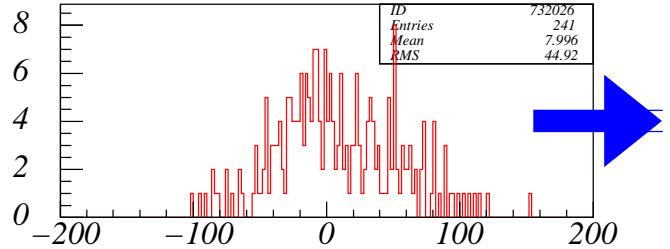
esum 4g consis.(Kp3)(tagging(NG4) wo emiss)

4th gamma energy

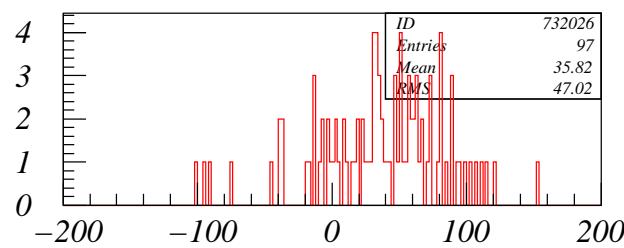


esum 3g consis. (Kp3)(tagging(NG4) wo emiss)

missing energy in rejection branch



esum 3g consis. (Kp3)(rejection(NG3) wo emiss)

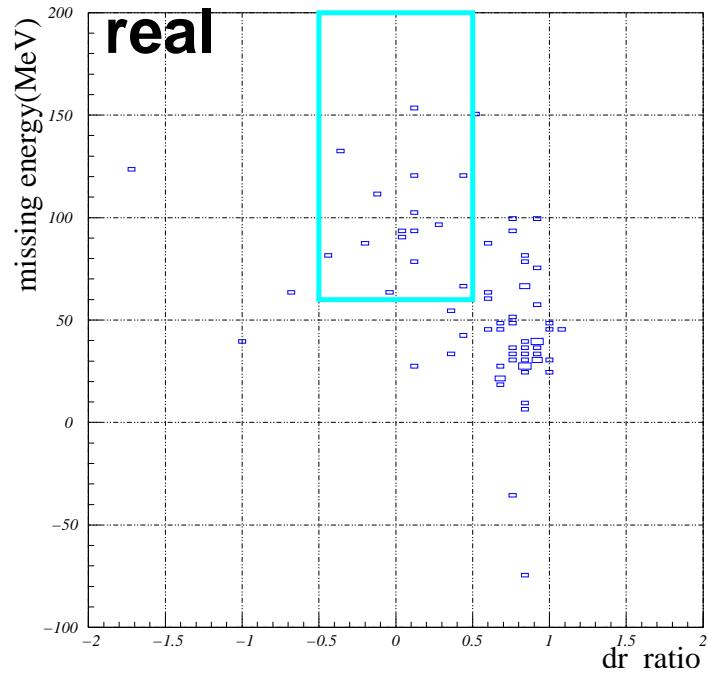
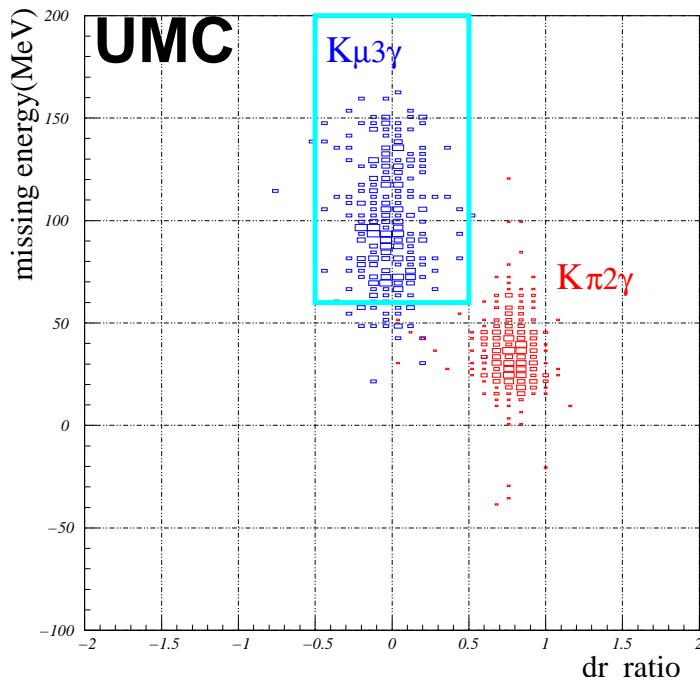


esum 3g consis. (Kp3)(rejection(NG3) wo emiss)

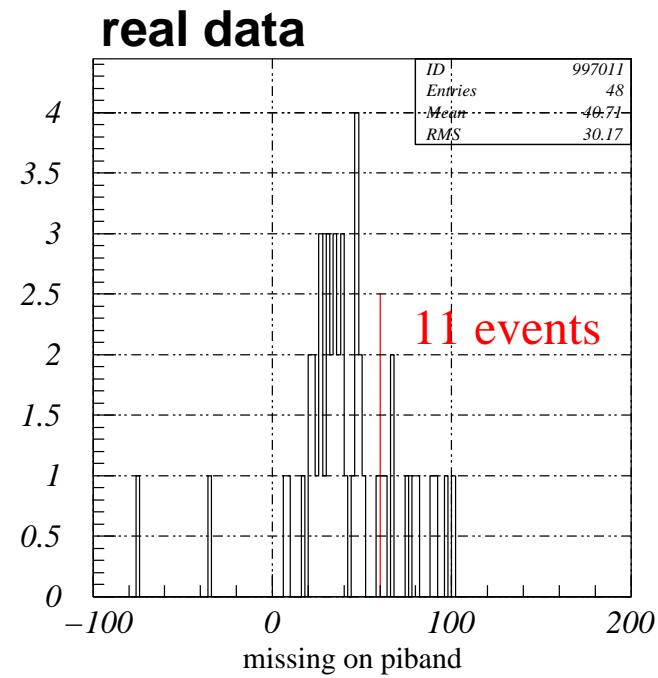
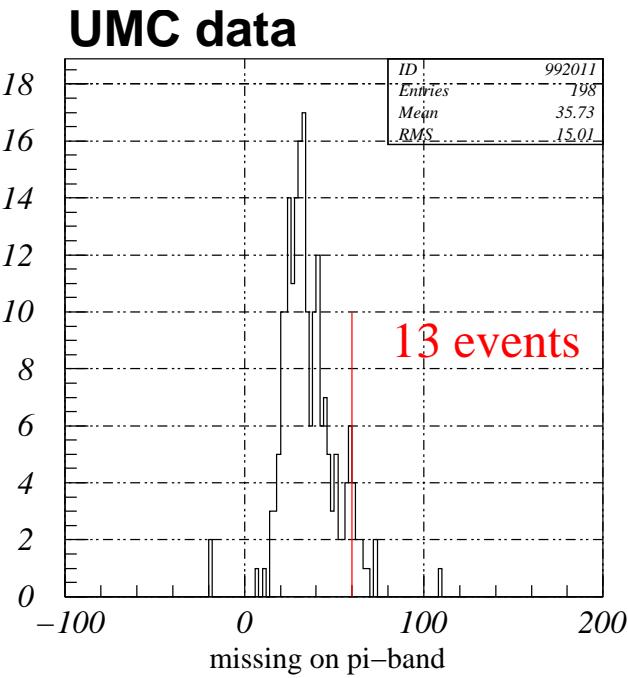
missing energy distribution at original rejection branch is zero consistent. But it is contrary to the inefficiency measurements.

$K_{\pi 2\gamma}$ background estimation

pure UMC-based estimation(using *corrected F_s*): $<0.194(90\% \text{CL})$

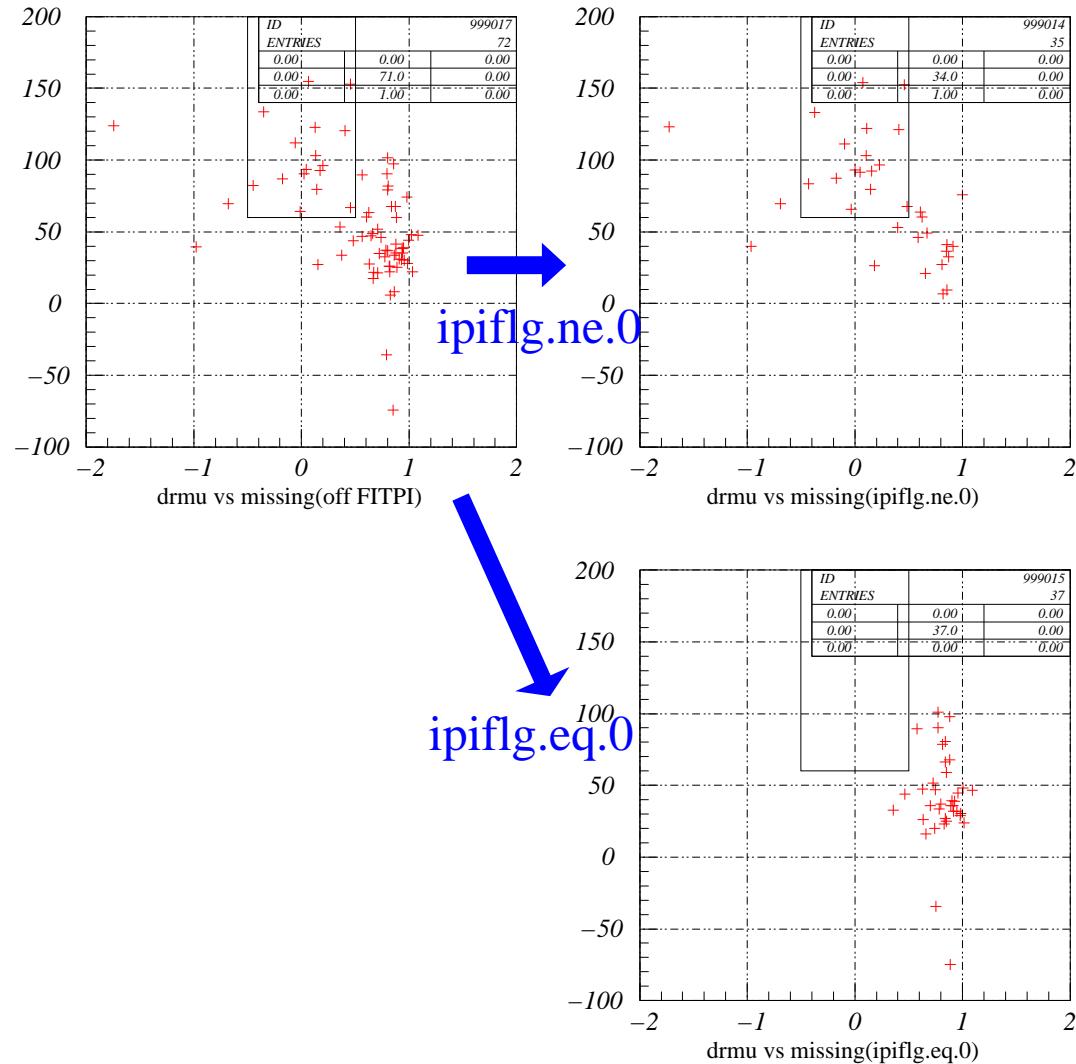


missing energy tail of $K_{\pi 2\gamma}$ peak



UMC doesn't reproduce missing energy distribution of real data.

FITPI check



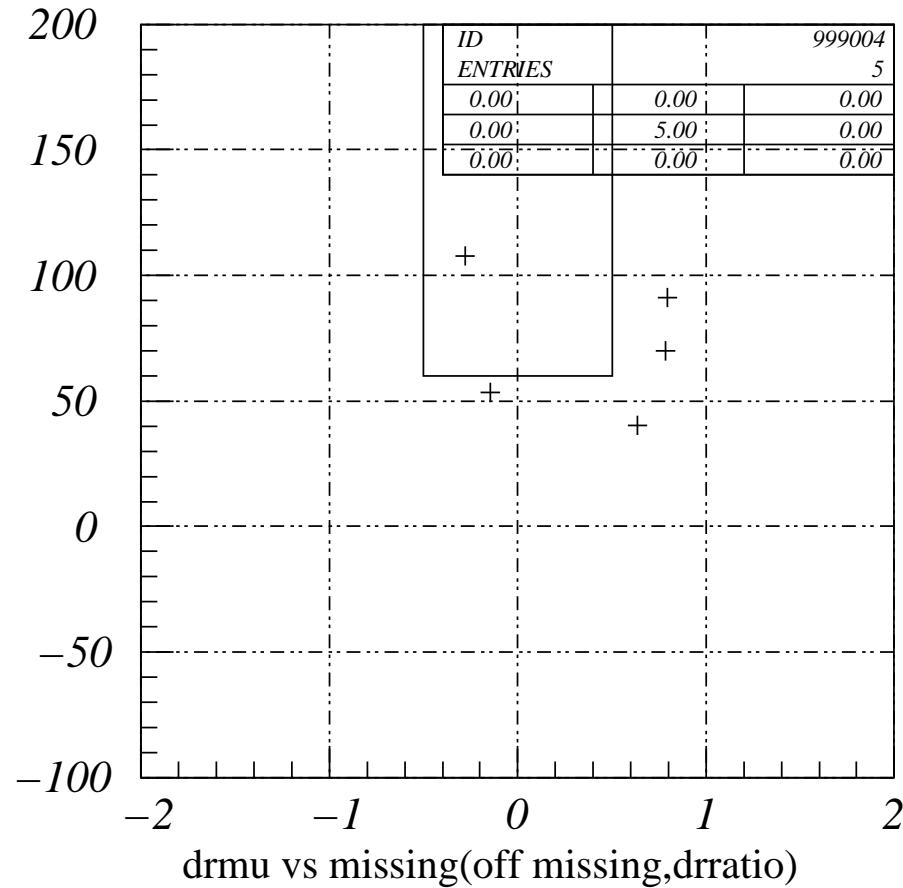
missing energy tail are consistent with pion

$K_{\pi 2}$ background possibility

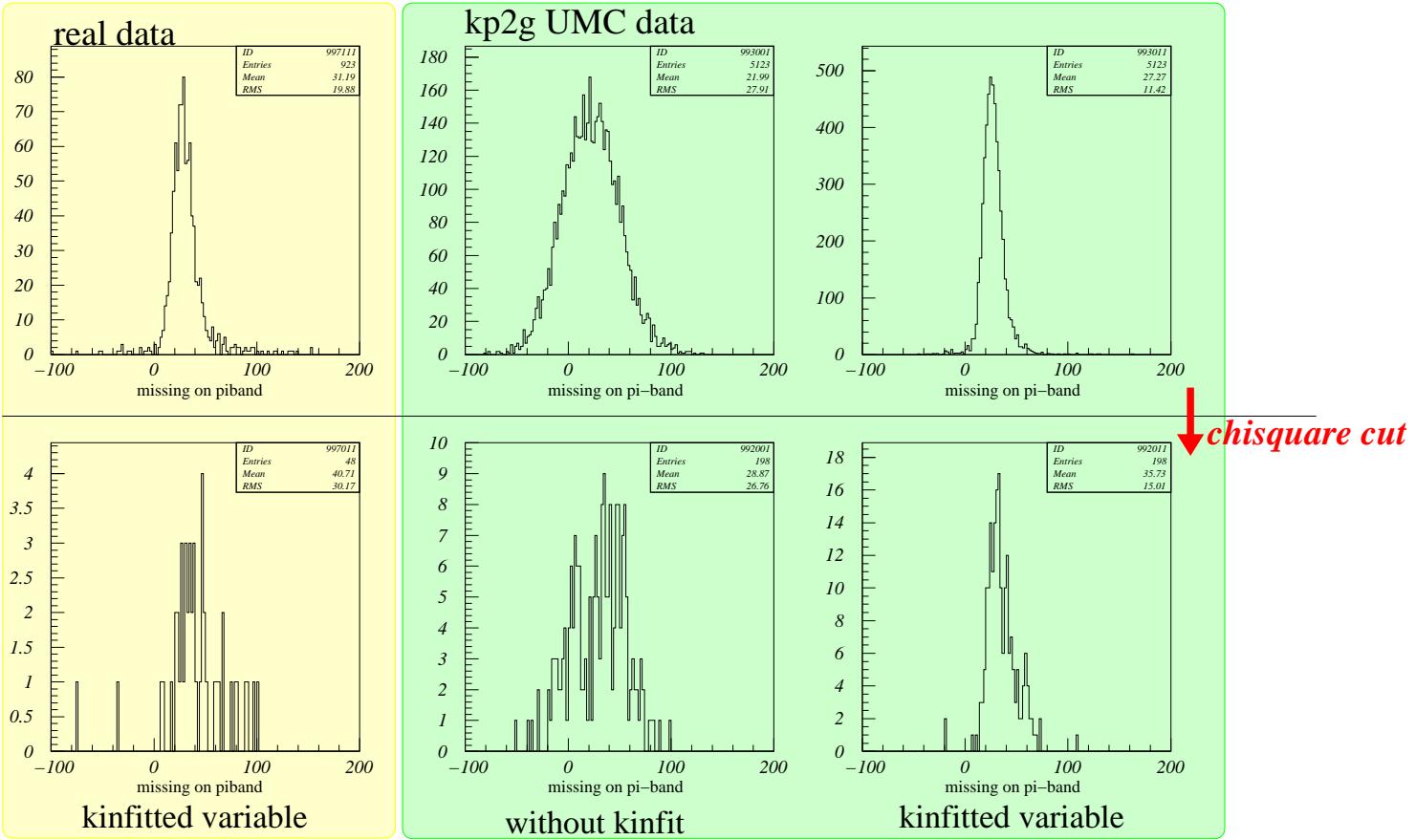
extra γ (accidental gamma / splitted gamma) is need for survival. No events enhanced when loosening the related cuts.

$K_{\pi 3}$ background possibility

UMC study shows no large $K_{\pi 3}$ contribution the distribution of 1.6 times larger kp3 decays



kinfit tuning problems



Inconsistency might comes from different kinfit tunings between UMC and real data.

mass $\mu\nu$ cut

If tail problems is set up by kinfit tuning, real enemy is decay-in-flight $K_{\pi 2\gamma}$. For this, $m_{\mu\nu}$ (invariant mass of muon and missing(calculated $K_{\mu 3\gamma}$ assumption)) cut will help.

Background summary

From 1/3 sample study

sources	#events
$K_{\pi 3}$	0.614+ <1.84
$K_{\pi 2\gamma}$	<0.194?
$K_{\mu 3} + Acc$	0.803
$K_{\mu 3} + \text{splitted } \gamma$???
$K_{e3}/K_{e3\gamma}$	0.505
All Backgrounds	1.92 +<2.03

$K_{\pi 2\gamma}$ study is still imperfect.

Acceptance Study F_s

3 measurements are tried. new

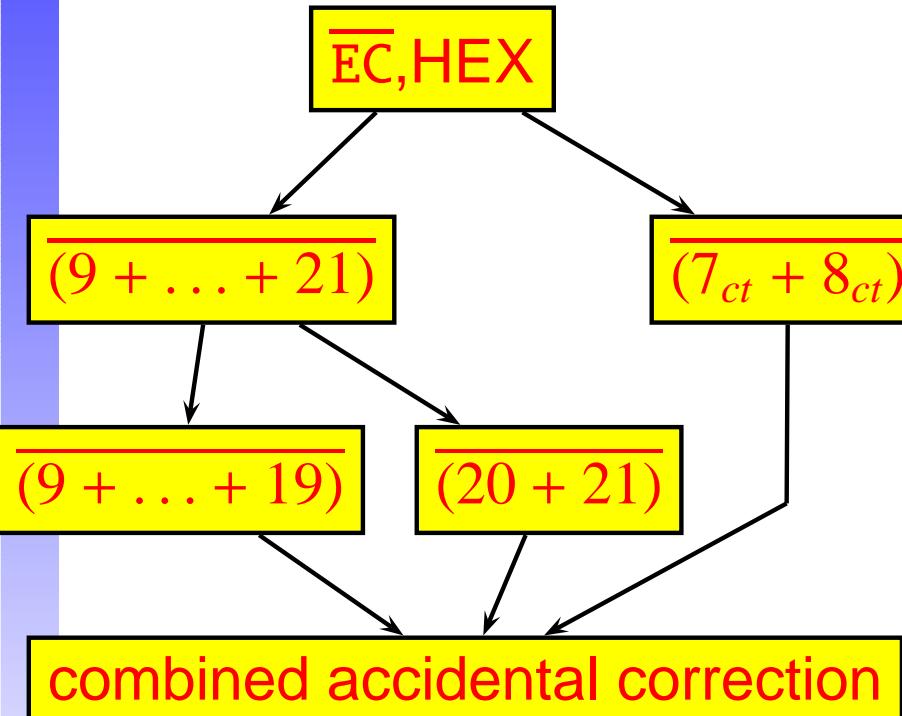
- ★ $K_{\pi 2}$ -based $F_s(Kp2(1))$ 0.740
- ★ $K_{\mu 2}$ -based $F_s(Km2(1))$ 0.719
- ★ $K_{\pi 3}$ -based $F_s(3\text{gamma})$ 0.273
- ★ $K_{\pi 2\gamma}$ -based(3gamma) 0.438
(according to the method of TN371.)

F_s from 3gamma data is quite different...

accidental loss correction(1)

Veto conditions must be corrected.

'98 3gamma trigger \equiv
 $KB \cdot DC \cdot T\bullet2 \cdot (3_{ct} + 4_{ct}) \cdot \overline{(7_{ct} + 8_{ct})} \cdot \overline{(9 + \dots + 21)} \cdot \overline{EC} \cdot HEX \cdot NG3$



$$\begin{aligned}\overline{EC}, HEX &\Leftarrow K_{\mu 2} \text{ in Kp2(1)} \\ &\Rightarrow 0.882 \\ \overline{(9 + \dots + 21)} &\text{ (direct estimation impossible)} \\ \overline{9 + \dots + 19} &\Leftarrow \pi\text{-scat} \\ &\Rightarrow 0.707 \\ \overline{20 + \dots + 21} &\Leftarrow K_{\mu 2} \text{ in Kp2(1)} \\ &\Rightarrow 0.965 \\ \overline{(7_{ct} + 8_{ct})} &\Leftarrow \text{offline analysis} \\ &\Rightarrow 0.991\end{aligned}$$

(combined accidental correction factor) = $0.601 \sim 0.623$

accidental loss correction(2)

corrected $F_s = 0.438 / (\text{accidental loss correction factor})$
 $= 0.70 \sim 0.73$

After accidental correction, consistent with $K_{\mu 2}$ -based/ $K_{\pi 2}$ -based
 F_s

miss measurement in $K_{\pi 3}$ tagging??

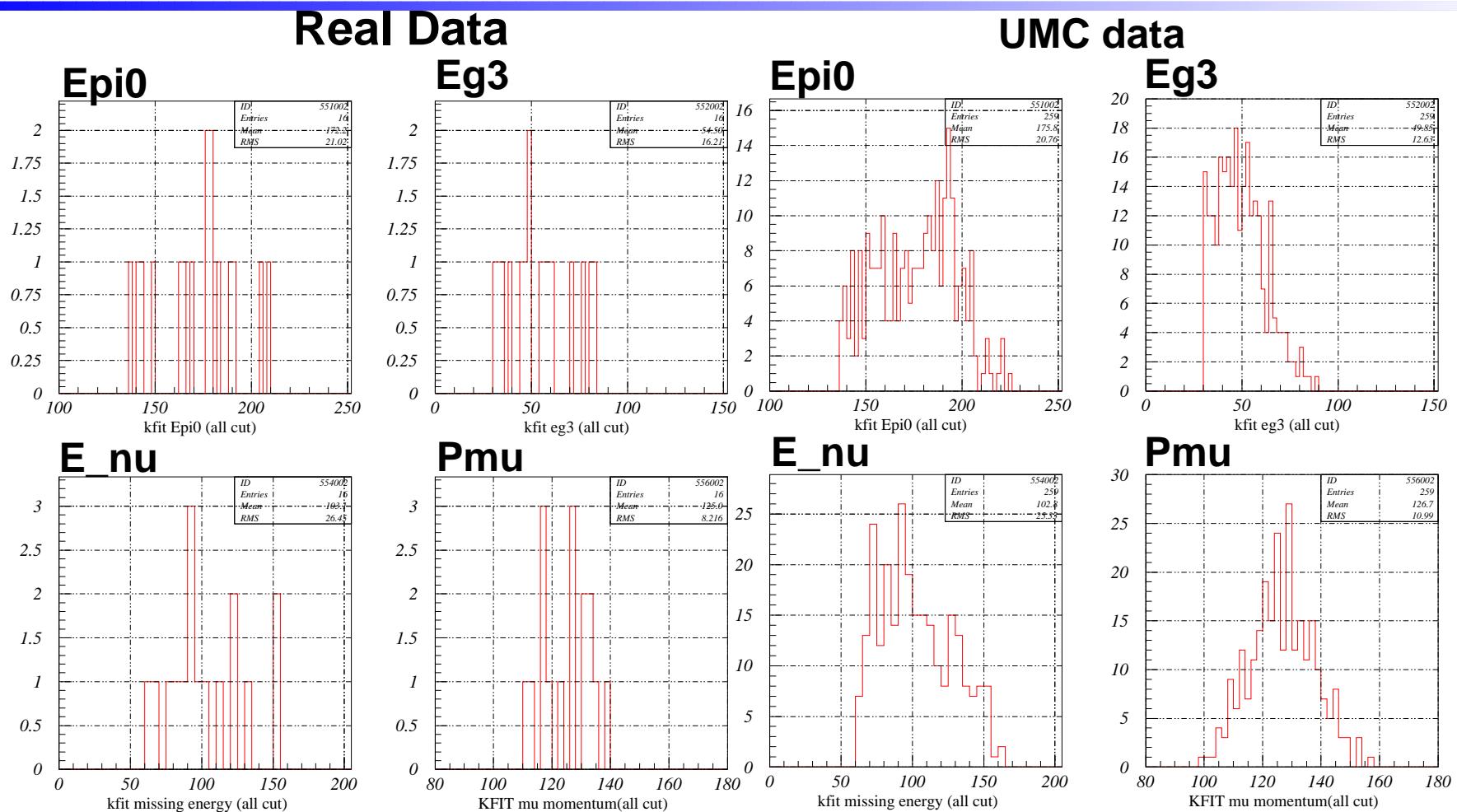
Expected Signals

$K_{\mu 3\gamma}$ acceptance for signal region: $\frac{492}{4.0 \times 10^7 \text{decays}} = 1.23 \times 10^{-5}$

1/3 samples

#ExpectedSignals(UMC) = KB_L \times Acceptance(UMC) \times Br \times F_s
= 19.6 events

Signal Candidates in 1/3 samples



Analysis schedule

Problems

- ★ $K_{\pi 2\gamma}$ background estimation is still imperfect
- ★ kinfit tuning consistency(or do away with kinematic fitting)
- ★ cut position optimazition(S/N improvements)

Full(or 2/3) sample study

- ★ background estimation consistency check
- ★ Physics result

Summary

- ★ Estimated the number of possible backgrounds
- ★ Check the Prospects for $K^+ \rightarrow \pi^0 \mu^+ \nu_\mu \gamma$
 - ~ 50 events with about 10% background

TODO

- ★ $K_{\pi 2\gamma}$ background study.
- ★ Positive Evidence of signal
good final plot(s)
- ★ Physics Results